3ND-P&PO-2491

UNCLASSIFIED

PLASTEC COPY
PLASTEC Ref. 1174
ADL Ref. 440

DOVER, N. J.

RESEARCH AND DEVELOPMENT REPORT
ON THE
APPLICATION OF ULTRASONICS TO THE
NON-DESTRUCTIVE TESTING OF
FIBER GLASS REINFORCED PLASTICS

Lab. Project 6188, Progress Report 3

Project No. SR007-03-04
Identification No. 18-1010-1

5 October 1960

W. Hand

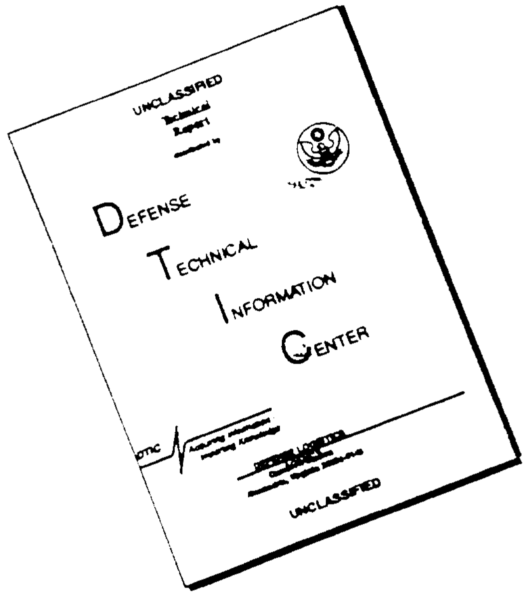
TECHNICAL REPORT

MATERIAL LABORATORY
NEW YORK NAVAL SHIPYARD
BROOKLYN 1, NEW YORK

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

3ND-NYNS-900-P-1A

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

-MSG DI4 DROLS PROCESSING-LAST INPUT IGNORED

-MSG DI4 DROLS PROCESSING - LAST INPUT IGNORED

-- 1 OF 1
-- ***DTIC DOES NOT HAVE THIS ITEM***
-- 1 - AD NUMBER: D431177
-- 5 - CORPORATE AUTHOR: NEW YORK NAVAL SHIPYARD BROOKLYN MATERIAL LAB
-- 6 - UNCLASSIFIED TITLE: RESEARCH AND DEVELOPMENT REPORT ON THE
-- ULTRASONICS TO THE NON-DESTRUCTIVE TESTING OF FIBER GLASS
-- REINFORCED PLASTICS.
-- 9 - DESCRIPTIVE NOTE: PROGRESS REPT., NO, 3,
--10 - PERSONAL AUTHORS: HAND,W. ;
--11 - REPORT DATE: OCT 05, 1960
--12 - PAGINATION: 27P
--20 - REPORT CLASSIFICATION: UNCLASSIFIED
--22 - LIMITATIONS (ALPHA): APPROVED FOR PUBLIC RELEASE; DISTRIBUTION
-- UNLIMITED. ~~AVAILABILITY: NEW YORK NAVAL SHIPYARD, MATERIAL LAB,~~
-- ~~BROOKLYN, N.Y. THIS PLACE IS NOW DEFUNCT.~~
--33 - LIMITATION CODES: 1 [redacted]

-- END Y FOR NEXT ACCESSION END

Alt-Z FOR HELP3 ANSI 3 HDX 3 3 LOG CLOSED 3 PRINT OFF 3 PARITY

RESEARCH AND DEVELOPMENT REPORT
ON THE
APPLICATION OF ULTRASONICS TO THE
NON-DESTRUCTIVE TESTING OF
FIBER GLASS REINFORCED PLASTICS

Lab. Project 6188, Progress Report 3

Project No. SR007-03-04
Identification No. 18-1010-1

5 October 1960

W. Hand

Materials Development Branch
D. H. Kallas, Head

Technical Director
GEO. J. DASHEFSKY

The Director
I. F. FIKE, CAPTAIN, USN

MATERIAL LABORATORY
New York Naval Shipyard
Brooklyn 1, New York

TABLE OF CONTENTS

	Page
ADMINISTRATIVE INFORMATION	4
OBJECT	4
BACKGROUND	4
DESCRIPTION	5
PROCEDURE AND RESULTS	6
CONCLUSIONS	12
FUTURE WORK	12
DISTRIBUTION LIST	

APPENDIX

A - Trip Report of Visit to Branson Instruments Incorporated (2 pages)

B - Trip Report of Visit to Avco Research and Advanced Development Laboratories (2 pages)

C - Sonoray Model 5 Specifications and Price (2 pages)

FIGURES

1 - Photo L18755-1, Ultrasonic Inspection of Large Delamination

2 - Photo L18755-2, Ultrasonic Inspection of 12 Inch Long Laminate

3 - Photo L18755-3, Ultrasonic Inspection of Mat Laminate Containing Voids and Porosity

TABLE OF CONTENTS
(Continued)

FIGURES

4 - Photo L18755-4, Ultrasonic Inspection of Bond Quality of Two Bonded Laminates

5 - Photo L18755-5, Ultrasonic Inspection of Resin-Rich Area in Woven Roving Laminate

6 - Ultrasonic Thickness Measurement of Polyester Glass Laminates by Through Transmission

7 - Ultrasonic Thickness Measurement by Pulse-Echo Technique

8 - Ultrasonic Thickness Measurements at 1.0 and 2.25 Megacycles

9 - Relationship Between Sound Velocity and Glass Content of Polyester-Glass Laminates

Lab. Project 6188
Progress Report 3

ADMINISTRATIVE INFORMATION

Ref: (a) BUSHIPS ltr A11/SR007-03-04(342C4), Ser 342C-676 of 2 Oct 1959
(b) Battelle Memorial Institute Final Report, Contract NObs 72388 of 14 Feb 1959
(c) COMNAVSHIPYDNYK MATLAB Project 6188, Progress Report 1 of 22 Jan 1960
(d) COMNAVSHIPYDNYK MATLAB Project 6188, Progress Report 2 of 25 May 1960
(e) Non-destructive Testing Handbooks, Edited by Robert C. McMaster, Ronald Press Co., N.Y. 1959
(f) Watertown Arsenal Laboratories Report WAL TR 143/33 Nov 1959, Ultrasonic Methods for Near-Surface Flaw Detection

1. Investigations and development of methods for the non-destructive inspection of reinforced plastic end-items are continuing at the Material Laboratory. The effort of the past quarter, June - September 1960, was directed toward the exploration and development of ultrasonic techniques for this purpose and specifically towards the determination of the capabilities of the Branson "Sonoray Model 5" ultrasonic tester.

OBJECT

2. The purpose of this project is to investigate and develop methods for the non-destructive inspection and testing of glass reinforced plastic end-items for Naval use.

BACKGROUND

3. Progress Reports 1 and 2 described the results of Material Laboratory investigations of the Battelle Memorial Institute's Dielectric Tester and the Laboratory's conclusions regarding this instrument's ability to meet the non-destructive testing objectives of this program. Briefly, the dielectric tester was judged unsuitable for the following reasons:

a. Inability to discriminate between thickness variations and other defects which produce similar response in the instrument.

b. Small depth of penetration of its electric field, limiting its applicability to laminates of thicknesses under 1/2 inch.

c. Non-linear field distribution, resulting in variation in sensitivity with depth of laminate. Thus, a flaw near the surface of a 1/2 inch thick sample was detectable from the near side, but "invisible" from the opposite side.

4. To become familiar with the present state of non-destructive testing in industry, visits were made to the Lycoming Division, the Research and Advanced Development Laboratories of the Avco Corporation, and to Branson Instruments, Incorporated. The findings at the Lycoming Division were reported in reference (d). The reports of the visits to Branson Instruments, Incorporated and the RAD Laboratories are included here as Appendix A and Appendix B, respectively. In view of the information obtained through the above visits and literature search, it was decided that ultrasonic methods offer the most promising approach to the subject problem. Consequently a Branson "Sonoray Model 5" ultrasonic tester was rented for use in this phase of the program.

DESCRIPTION

5. The Branson "Sonoray Model 5" pulse-echo ultrasonic flaw detector was selected as typical of instruments which are commercially available under other trade names such as "Reflectoscope", "Immerscope", "Sonizon", etc. The specifications and price of this instrument are given in Appendix C.

6. The principles of operation of ultrasonic flaw detecting instruments are well described in reference (e). With ultrasonics, inspection is usually performed by one of two basic methods, both of which involve the projection of a beam of ultrasonic energy into the specimen by means of a piezoelectric crystal transducer. In the through transmission method the energy transmitted is received by another transducer. In the pulse-echo method the energy is reflected from discontinuous areas and boundaries in the material and received by the same transmitting transducer. Oscilloscope display is the usual form of presentation of the resultant information in both procedures. Inspection is accomplished because the ultrasonic beam travels with little loss through homogeneous material except when it is intercepted and reflected by discontinuities. Flaws can be detected by energy reflected back to the transducer or by a reduction of transmitted energy.

7. In addition to flaw detection, ultrasonic techniques may be applied to thickness measurements, study of material composition and structure, determination of elastic moduli, evaluation of processing variables on the specimen, and estimating physical strength properties of structural materials. It is likely that other uses for ultrasonic testing will be developed in time.

8. The advantages afforded by ultrasonic testing may be listed as follows:

a. High sensitivity, permitting the detection of small defects.

b. Great penetrating ability, allowing examination of extremely thick sections.

c. Accuracy in the measurement of flaw position and estimation of flaw size.

d. Fast response permitting rapid and automated inspection.

e. Need for access to only one surface of the specimen for reflection type testing.

f. Portability.

9. Limitations to ultrasonic testing usually relate to the following factors:

a. Unfavorable sample geometry involving size, contour, complexity and defect orientation.

b. Adverse internal structure such as porosity.

c. The need for a liquid medium such as water, oil or glycerine as a coupling agent between the transducer and the sample.

d. Unfavorable material internal structure resulting in excessive signal attenuation and spurious reflections.

PROCEDURE AND RESULTS

10. Measurements and inspections were conducted at 0.4, 1.0, and 2.25 megacycles. Invariably, 1.0 megacycle operation of the equipment produced best results with reinforced plastics. Consequently, the bulk of the investigations were conducted at 1.0 megacycle.

11. The various aspects of ultrasonic testing explored were as follows:

a. DELAMINATION DETECTION

Laminar voids, delaminations, and other discontinuities are readily detected. Controlling factors are size of defect, its orientation with respect to the plane of the transducer, the attenuation of signal due to the material, and the distance between the flaw and the transducer. A typical example of ultrasonic response obtained from a delamination is shown in Figure 1. The delaminated sample used was the same one described in the report of reference (b), Figure 10. In reference (b) this flaw was described as only detectable from the near side. In the present report Figure 1 illustrates that this same delamination may be detected from either side by ultrasonics. The laminate was 1/2 inch thick, fire retardant, polyester resin, reinforced with glass mat. Large laminar flaws, about 1/8 inch from one surface, were intentionally fabricated into the panel to produce the desired defects. In Figure 1, the defect is not only made apparent by the strong reflected pulse, but also by the accompanying large reduction in reflection from the back surface (back reflection) due to interference presented by the defect. The location of the defect with respect to the front and back surfaces of the laminate may be evaluated from the locations of the various pulses.

b. INSPECTION OF THICK SECTIONS

Thick sections of laminate may be ultrasonically inspected provided porosity does not excessively attenuate the signal. Figure 2 illustrates the results of ultrasonic inspection through a 12 inch length of glass cloth polyester, one inch thick, having a 1 inch diameter hole drilled about 8 inches from one end.

(1) Figure 2A shows inspection by pulse-echo technique. Since the signal is reflected from the back surface its actual travel distance is twice the length of the specimen. To provide sufficient energy for such a long transmission path the transducer was operated with reduced damping giving rise to the extensive "ringing" or reverberation visible in the outgoing pulse of this oscillogram. The reflection from the hole, however, is readily distinguished from the "ringing" and its location from the ends of the laminate is apparent.

(2) In Figure 2B, the same sample was measured by through transmission technique. Here, the signal path was only 12 inches and much less power was needed. Since through transmission responds to defects by reduction in amplitude of the received signal, the existence of the hole was indicated by a 90% decrease in received pulse amplitude when compared to transmission through the surrounding, defect-free, material. Figure 2B shows transmission through defect-free material. Transmission through the obstructing hole is not shown, but is identical except for a greatly reduced received pulse.

c. DETECTION OF VOIDS AND POROSITY

Voids and porosity may be detected by either pulse-echo or through-transmission techniques. In both methods the display is similar, consisting of an outgoing pulse and a back reflection or received signal. The presence of voids or porosity is indicated by a reduction in amplitude of the back reflection, or in the received pulse, as shown in the oscillograms of Figure 3. By scanning, defective areas may be mapped and the extent and degree of porosity determined by comparison of reflected pulse amplitudes.

d. BOND QUALITY

A poor bond and a delamination are physically similar, and consequently their ultrasonic responses have much in common. Figure 4, showing the contrast in reflected signal between a good and a poor bond, is similar to the oscillograms of Figure 1 except for the relative locations of the defects. A bond defect can be distinguished from a delamination, ultrasonically, insofar as the reflection from the defect indicates it's location at the bond line. This is determined by the position of the leading edge of the reflection with respect to the leading edges of the outgoing pulse and back reflection. Poorly bonded areas may be outlined by scanning and evaluation of strength and quality may be accomplished by comparison with reflection amplitudes of acceptable bonds. Essentially, the greater the amplitude of the bond reflection, the poorer the bond.

e. DETECTION OF RESIN-RICH AREAS

Figure 5 shows oscillograms illustrating the ultrasonic detection of a resin-rich area in a polyester-glass woven roving laminate. This is the laminate of Figures 7 and 8 of reference (b) in which this defect was measured by dielectric means. The boundary reflections shown in Figure 5 are produced by the difference in acoustic impedance between the resin-glass and the pure resin media. In Figure 5 it is demonstrated that the defect is observable from either side of the panel. When inspected with the Battelle Dielectric Tester the resin-rich area was detectable only from the defective side. It is also observed in Figure 5 that a stronger outgoing pulse was needed in the resin-rich laminate inspection to produce a boundary reflection roughly equivalent to the delamination reflection of Figure 1. The reason for this may be explained by the following considerations:

The relationship between reflection coefficient, R, and the acoustic impedances, Z_1 and Z_2 of two media, is given by Equation (1) below:

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2 \qquad \text{Eq. (1)}$$

In Equation (1), acoustic impedance is the product of the velocity of compressional sound waves in a medium and the density of that medium. When acoustic impedance values, taken from reference (e), are inserted in Equation (1) it is found that the reflection from a laminate-air boundary such as a delamination is practically 100%, whereas a resin-rich boundary has a reflection coefficient of about 15%. This effect may be utilized in determining which of the two types of defects are present. An additional aid in distinguishing between the two defects is the small loss of back reflection for the resin-rich defect when compared to the large decrease in back reflection for a delamination defect.

f. THICKNESS GAGING

Using the same group of polyester-glass cloth laminates of uniform composition and various thicknesses, employed in reference (b) (Figure 5), investigations were conducted to determine the most suitable method of non-resonant ultrasonic thickness gaging.

(1) Both pulse-echo and through transmission techniques were employed with highly damped outgoing signal to obtain narrow pulse widths. Two methods of measurement were employed as follows:

(a) Measurement of the horizontal distance between the peak of the outgoing pulse to the peak of the back reflection or received pulse, and

(b) Measurement of the horizontal distance between the leading edges of these pulses.

(2) The results of these measurements are shown plotted against actual laminate thicknesses in Figures 6 and 7. The "Thickness Units on Screen" coordinate is an arbitrary scale whose values are a function of the "Range" setting of the instrument and are related to actual thickness by the relationship of Equation (2) below:

$$T_A = K\,T_S + T_T \qquad \text{Eq. (2)}$$

where:

T_A = actual thickness
T_S = Thickness units on Screen
T_T = Apparent Ultrasonic thickness of Transducer (Y - axis intercept of calibration curve)
K = Slope of calibration curve; obtainable from:

$$K = \frac{T_{S_2} - T_{S_1}}{T_{A_2} - T_{A_1}} \qquad \text{Eq. (3)}$$

Subscripts 1 and 2 in Equation (3) refer to a small and a large thickness value respectively, on the calibration curve.

(3) All procedures resulted in approximately equal accuracy, exhibiting a maximum error of 2% in the 1/8 to 1/2 inch range. The leading edge measurements were somewhat easier to conduct and are therefore prefered. In practice, a calibration curve such as shown in Figures 6 and 7 could be developed from ultrasonic measurements of known thicknesses of material of the same type as that requiring inspection. Thickness may then be computed from Equation (2) or taken directly from the calibration curve. In thickness gaging, it is essential that the instrument settings remain unchanged from those used in the calibration. This may be assured by checking against the known thickness standards.

(4) Although not employed in this investigation, vernier type attachments are available for facilitating and improving the accuracy of measurements taken from the instrument display screen. Resonant type ultrasonic instruments are also available with a primary function of thickness gaging. The "Vidigage" is such an instrument which is also manufactured by Branson Instruments Incorporated. This instrument, however, is more difficult to operate and has only limited application to flaw detection.

(5) Figure 8 shows the results of thickness measurements conducted at 1.0 and 2.25 megacycles using both pulse-echo technique and leading edge readings. Of the two frequencies the better accuracy was obtained at 1 MC due to superior resolution and transmission of the signal in reinforced plastics.

g. GAGING OF THICK LAMINATES

The results of the inspection of the 12 inch length of polyester-glass laminate described in paragraph 5b above and illustrated in Figure 2 indicate that large thicknesses may be gaged by techniques similar to those used in flaw detection and ordinary thickness gaging. The maximum thickness measureable has not been determined as it is a function of the attenuation of the laminate as well as the measuring capabilities of the instrument. In properly fabricated laminates, measureable thicknesses should be considerably greater than 12 inches. Where both sides of the laminate are accessible, through transmission measurement could provide twice the range obtainable with pulse echo technique.

h. GAGING AND INSPECTION OF THIN LAMINATES

Laminates less than 1/8 inch thick could not be measured for thickness or inspected for defects by the usual ultrasonic contact

cont'd

coupling techniques because of the finite duration of the outgoing pulse. The transit time of the outgoing pulse in traveling from the transducer through the laminate and back was shorter than the pulse length. Thus, the back reflection became superimposed on the transmitted pulse and was often indistinguishable. This problem has been investigated and solutions offered in connection with metallurgical ultrasonic testing in the report of reference (f). These solutions may also be applicable to reinforced plastics. Further investigations in this connection which may ultimately be applicable to sandwich type structures could be along the following lines:

(1) Where feasible, immersion testing, in which the transducer and laminate are separated by water may be employed. The transducer is positioned so that the reflections from the front and rear of the laminate are clear of the outgoing pulse. Both flaw detection and thickness gaging may be accomplished.

(2) Because of its short depth of penetration and restricted dielectric field configuration, the Battelle Dielectric Tester is expected to have its greatest effectiveness with thin laminates. With this instrument however, thickness variation cannot be distinguished from other defects, and the measurements must be supplemented with other discriminating techniques. In the case of thin, translucent, laminates visual examination could be effective as the supplementary inspection.

i. DETERMINATION OF RESIN-GLASS RATIO BY ULTRASONICS

The "Type A" oscilloscope display employed in the ultrasonic flaw detector lends itself to the measurement of sonic velocity of the medium through which its signal is transmitted. Since the velocity of sound is dependent upon the properties of the material it is possible to discriminate between similar appearing materials by means of their sonic properties. In the case of composite materials, such as polyester-glass laminates, it may be possible to determine the relative amounts of glass and resin by sonic velocities measurements. Figure 9 shows a computed curve of the expected variation of sonic velocity of polyester-glass laminates of various glass-resin compositions. The curve was computed from measurements of sonic velocities of pure, solid polyester resin and of pyrex glass rod. By means of a curve of this type and the measurement of sonic velocity in resin-glass composite laminates, it is expected that the proportions of glass and resin may be determined. This phase of the project is planned to be the subject of the next progress report.

CONCLUSIONS

The Branson "Sonoray Model 5"

12. ~~An~~ ultrasonic flaw detecting instrument ~~has been~~ was demonstrated to be capable of meeting most of the requirements expected in a versatile non-destructive testing tool for reinforced plastics. Many of the aspects of ultrasonic testing ~~have been~~ given only superficial treatment in this report since the objective at this stage is only to illustrate the nature of ultrasonics' capabilities. It is not expected that all testing problems that may arise in the field inspection of reinforced plastic end products can be anticipated and provided for in this program. As particular needs arise the techniques and equipment to meet these requirements will probably be developed once the underlying principles and capabilities of the instrument are understood.

13. ~~In summary,~~ It is concluded that ultrasonic non-destructive test methods may be applied to such diverse inspection requirements for reinforced plastics as:

a. Flaw detection (including the detection of delaminations, voids, porosity, resin-rich and resin starved areas),

b. Thickness gaging,

c. Bond quality, and

d. Inspection ~~and gaging of very thick sections~~.

e. Inspection from one side of laminate.

AUTHOR MODIFIED

14. The possibility also appears to exist for determining by ultrasonic non-destructive means, such properties of reinforced plastics as:

a. Resin-glass ratio.

b. Flexural, tensile and compressive strengths.

c. Compressive bulk modulus through velocity of compressional wave measurements in the material.

FUTURE WORK

15. The plans for the next quarter include continuation of the development of ultrasonic means for determining resin-glass content of laminates. Work is also planned to obtain the correlation of strength properties with

relative amplitude of back reflections. The feasibility of determining elastic moduli from sonic velocity measurements will also be investigated.

16. Ultimately, it will be necessary to establish criteria for the classification of defects into acceptable, repairable or rejectable levels for specification purposes. In addition, the search will continue for instruments capable of performing non-destructive testing functions beyond ultrasonic capabilities or in areas where other instruments have superior competence.

Approved:

D. H. KALLAS
Head, Materials Development Branch

nt

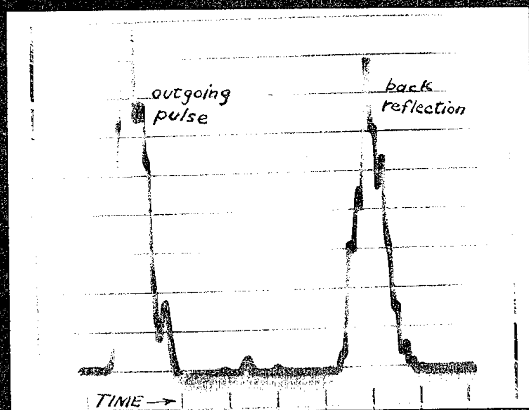


Fig. 1A- Transducer over material free of defects

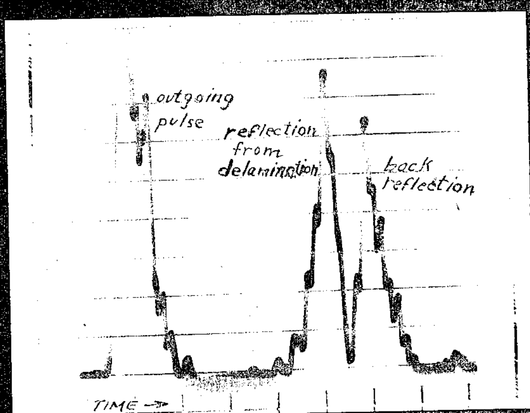


Fig. 1B- Transducer over large delamination defect located 1/8 inch from back surface

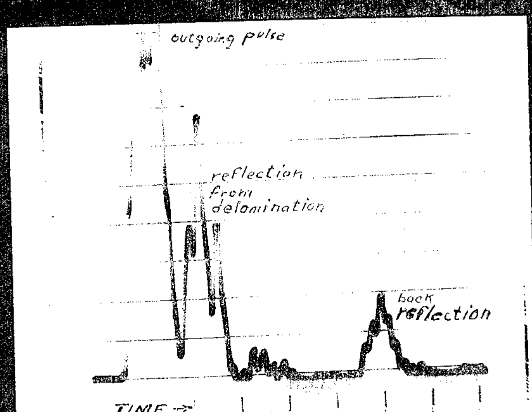


Fig. 1C- Transducer over opposite side of delamination. Defect 1/8 inch from transducer surface

MATERIAL LABORATORY

LAB PROJECT 6188

FIGURE 1 - ULTRASONIC INSPECTION AT 1MC OF 1/2 in. THICK POLYESTER MAT LAMINATE SHOWING EFFECTS OF A LARGE DELAMINATION (Note reduction of back reflection when defect is present)

PHOTO - L18755-1

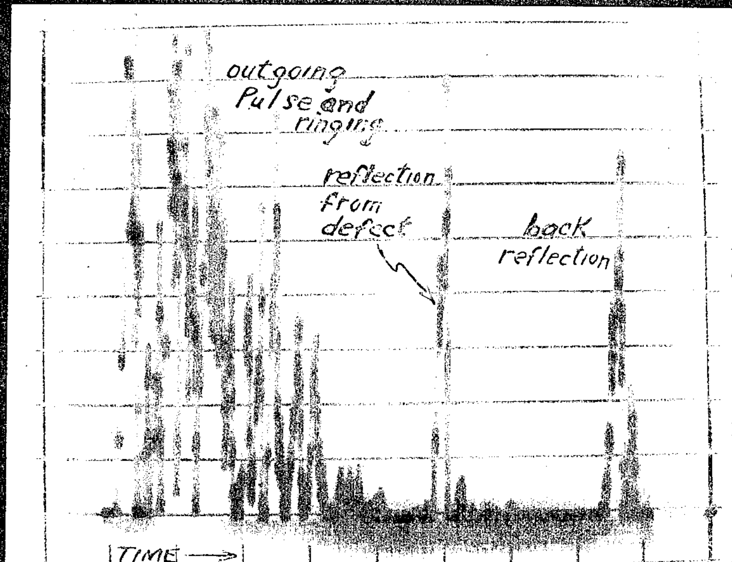


Fig. 2A- Pulse-echo transmission showing reflection from 1 in. dia. hole 8 in. from transducer. Extensive transducer ringing due to high input energy.

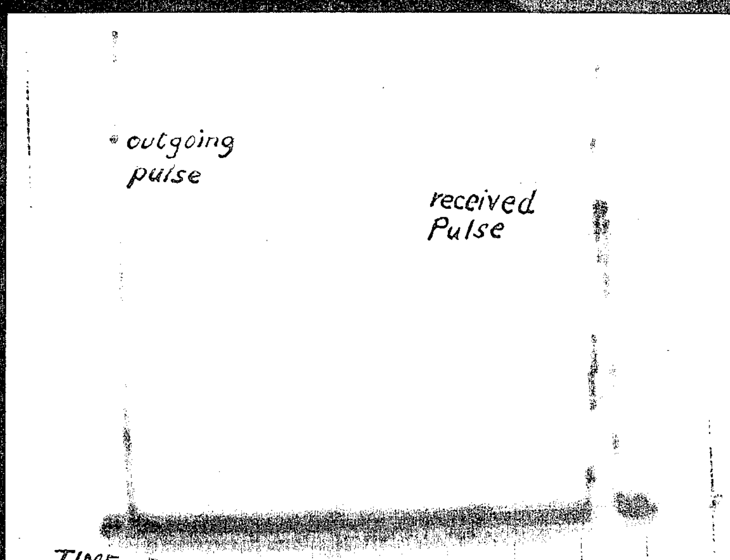


Fig. 2B- Through transmission inspection of 12 in. length. Effect of defect is to reduce amplitude of received pulse.

MATERIAL LABORATORY

LAB PROJECT 6188

FIGURE 2 - ULTRASONIC INSPECTION AT 1 MC. OF 12 in. LONG GLASS CLOTH POLYESTER LAMINATE 1 in. THICK

PHOTO - L18755-2

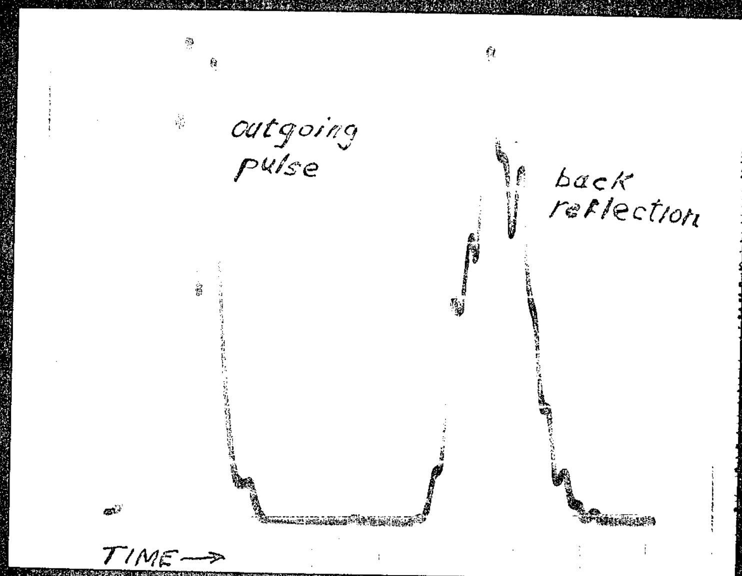


Fig. 3A- Transducer over material relatively free of defects

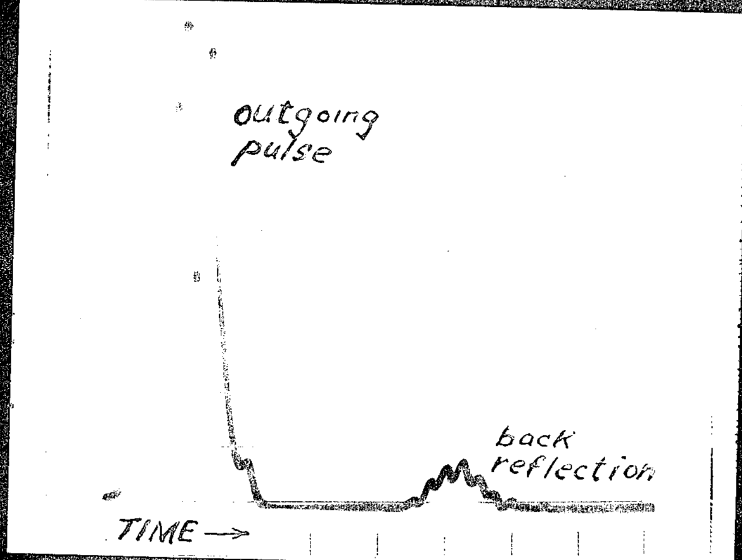


Fig. 3B- Transducer over porous area. Note large reduction in back reflection due to dispersion and absorption of signal.

MATERIAL LABORATORY LAB PROJECT 6188

FIGURE 3- ULTRASONIC INSPECTION AT 1 MC. OF 3/8 in. THICK MAT LAMINATE CONTAINING VOIDS AND POROSITY USING PULSE-ECHO TRANSMISSION

PHOTO - L18755-3

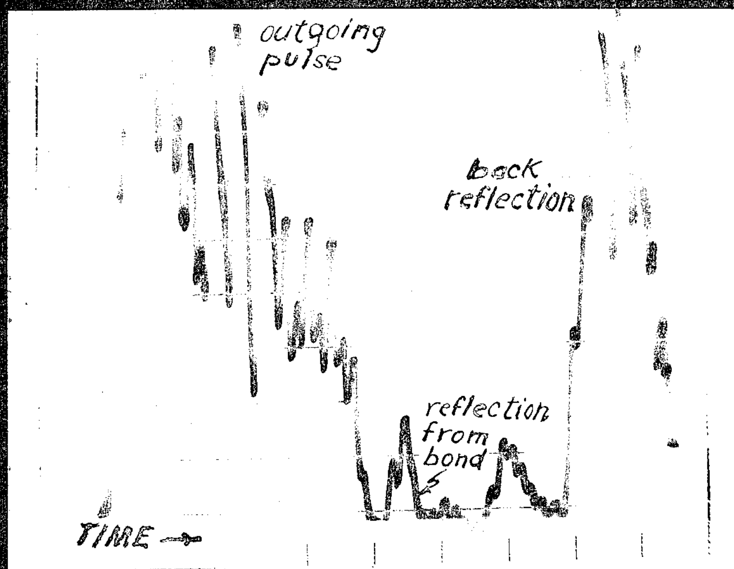


Fig. 4A- Transducer over relatively well bonded area.

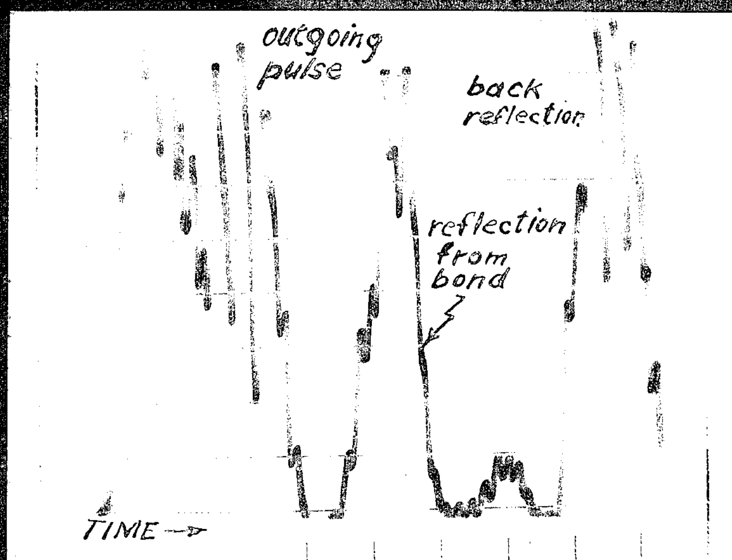


Fig. 4B- Transducer over relatively poorly bonded area. Note increased reflection from bond.

MATERIAL LABORATORY

LAB PROJECT 6188

FIGURE 4- ULTRASONIC INSPECTION AT 1MC. OF BOND QUALITY OF TWO 1/2 in. THICK PRESS BONDED POLYESTER GLASS CLOTH LAMINATES (Pulse-echo transmission)

PHOTO - L18755-4

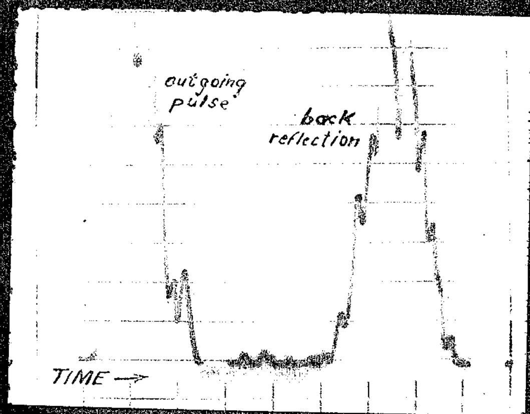


Fig. 5A- Transducer over material free of defects

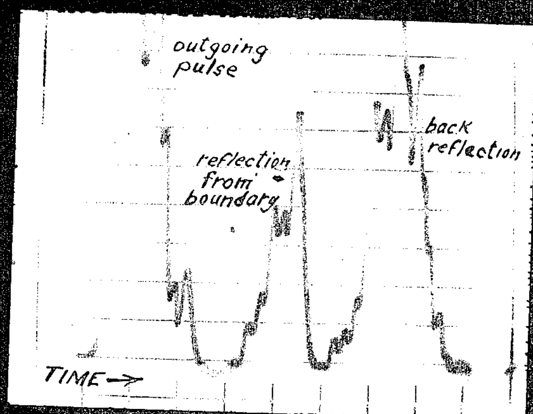


Fig. 5B- Transducer over resin-rich area. Defective area on transducer side of laminate. Reflection occurs at boundary between resin and resin-glass media.

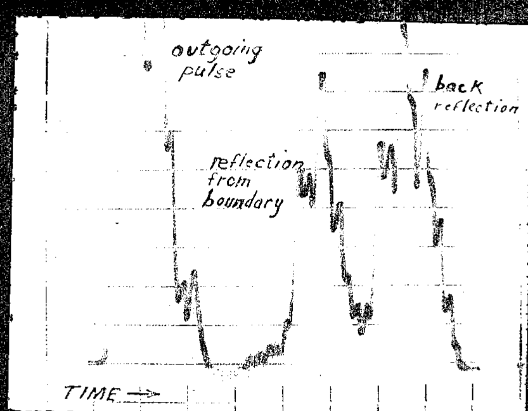


Fig. 5C- Resin-rich area on far side of transducer

MATERIAL LABORATORY

LAB PROJECT 6188

FIGURE 5 - ULTRASONIC INSPECTION AT 1 MC. FOR RESIN-RICH AREAS OF 1/2 in. THICK POLYESTER-GLASS WOVEN ROVING LAMINATE
(Pulse-echo transmission)

PHOTO - L18755-5

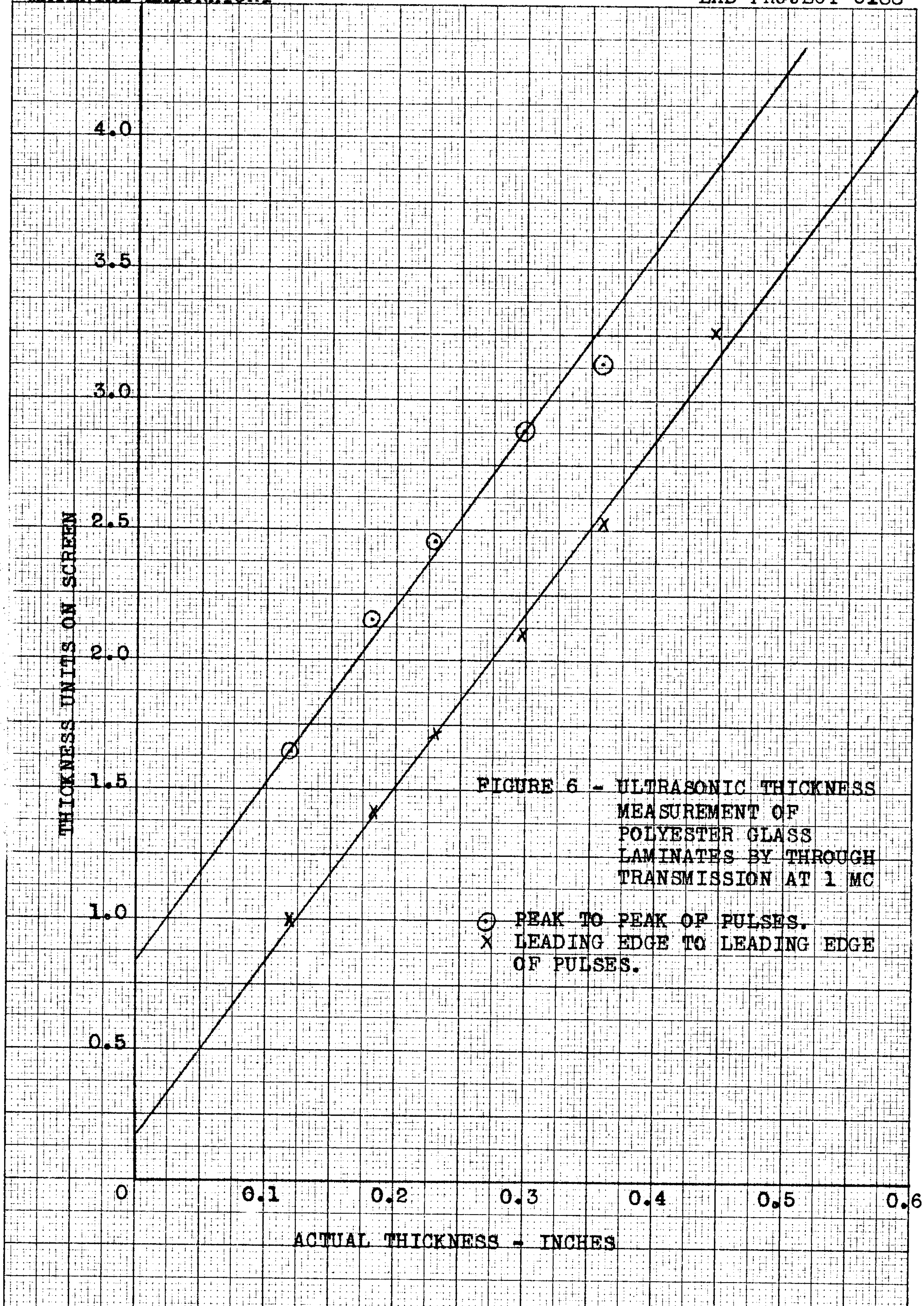


FIGURE 6 - ULTRASONIC THICKNESS MEASUREMENT OF POLYESTER GLASS LAMINATES BY THROUGH TRANSMISSION AT 1 MC

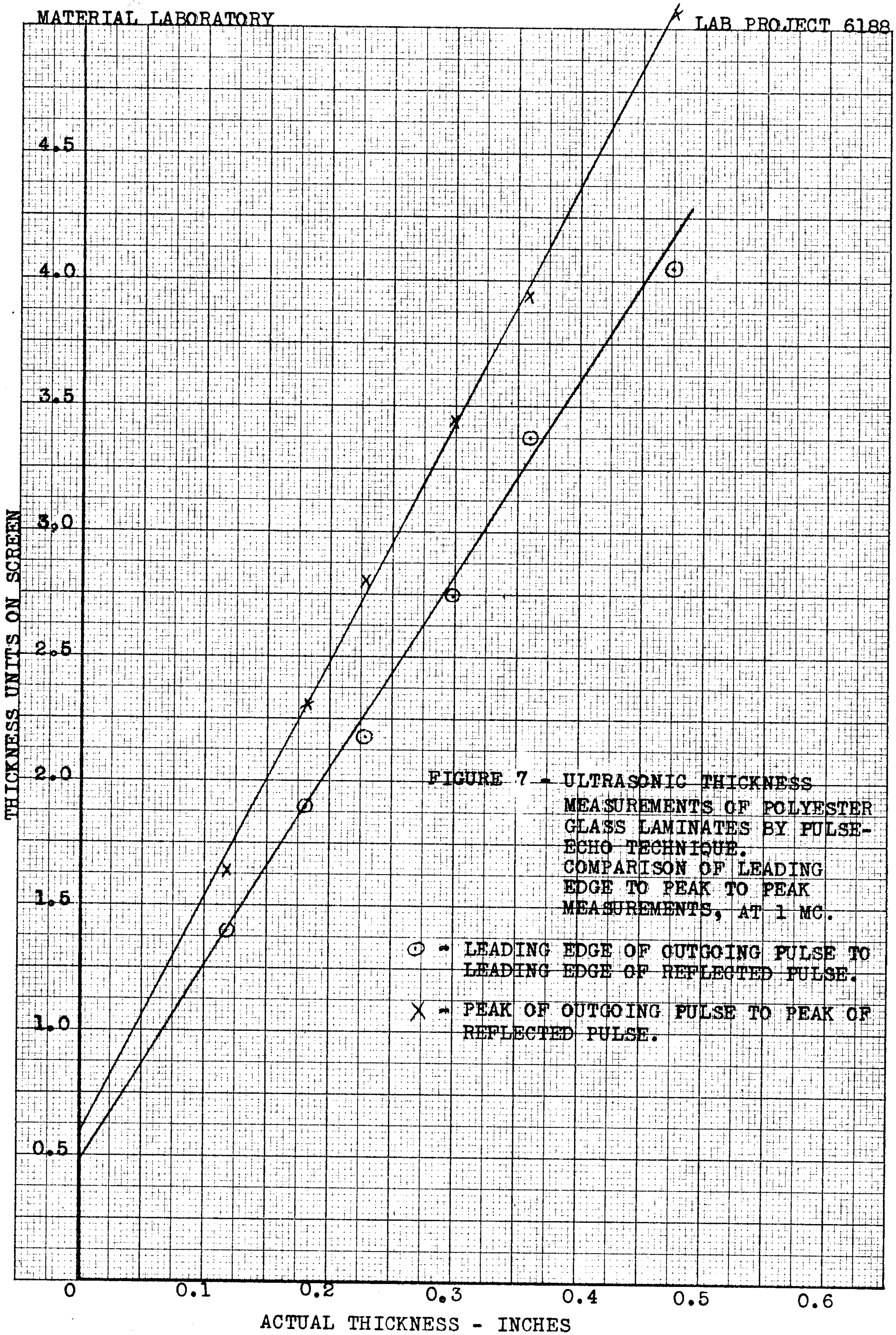


FIGURE 7 - ULTRASONIC THICKNESS MEASUREMENTS OF POLYESTER GLASS LAMINATES BY PULSE-ECHO TECHNIQUE. COMPARISON OF LEADING EDGE TO PEAK TO PEAK MEASUREMENTS, AT 1 MC.

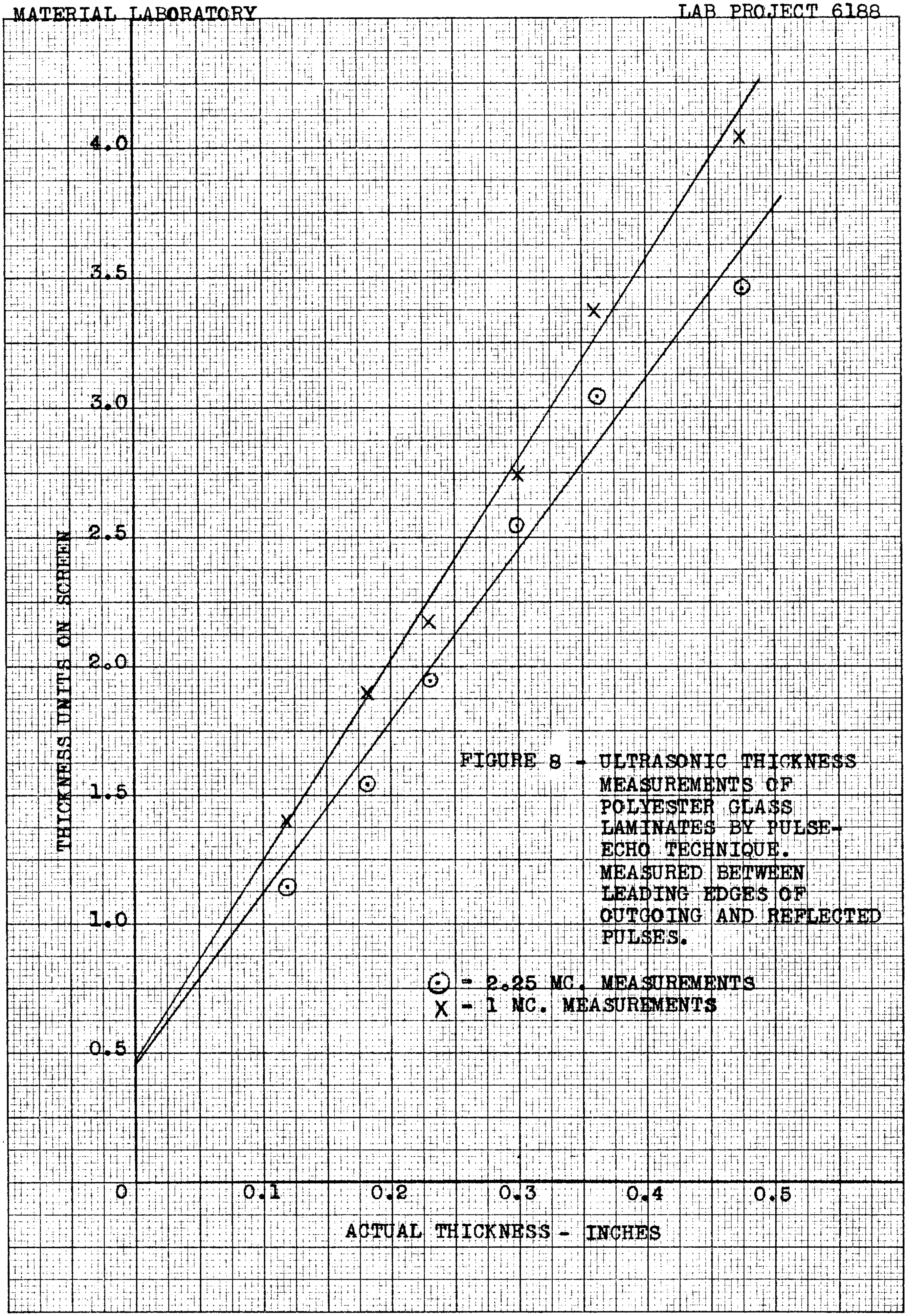


FIGURE 8 - ULTRASONIC THICKNESS MEASUREMENTS OF POLYESTER GLASS LAMINATES BY PULSE-ECHO TECHNIQUE. MEASURED BETWEEN LEADING EDGES OF OUTGOING AND REFLECTED PULSES.

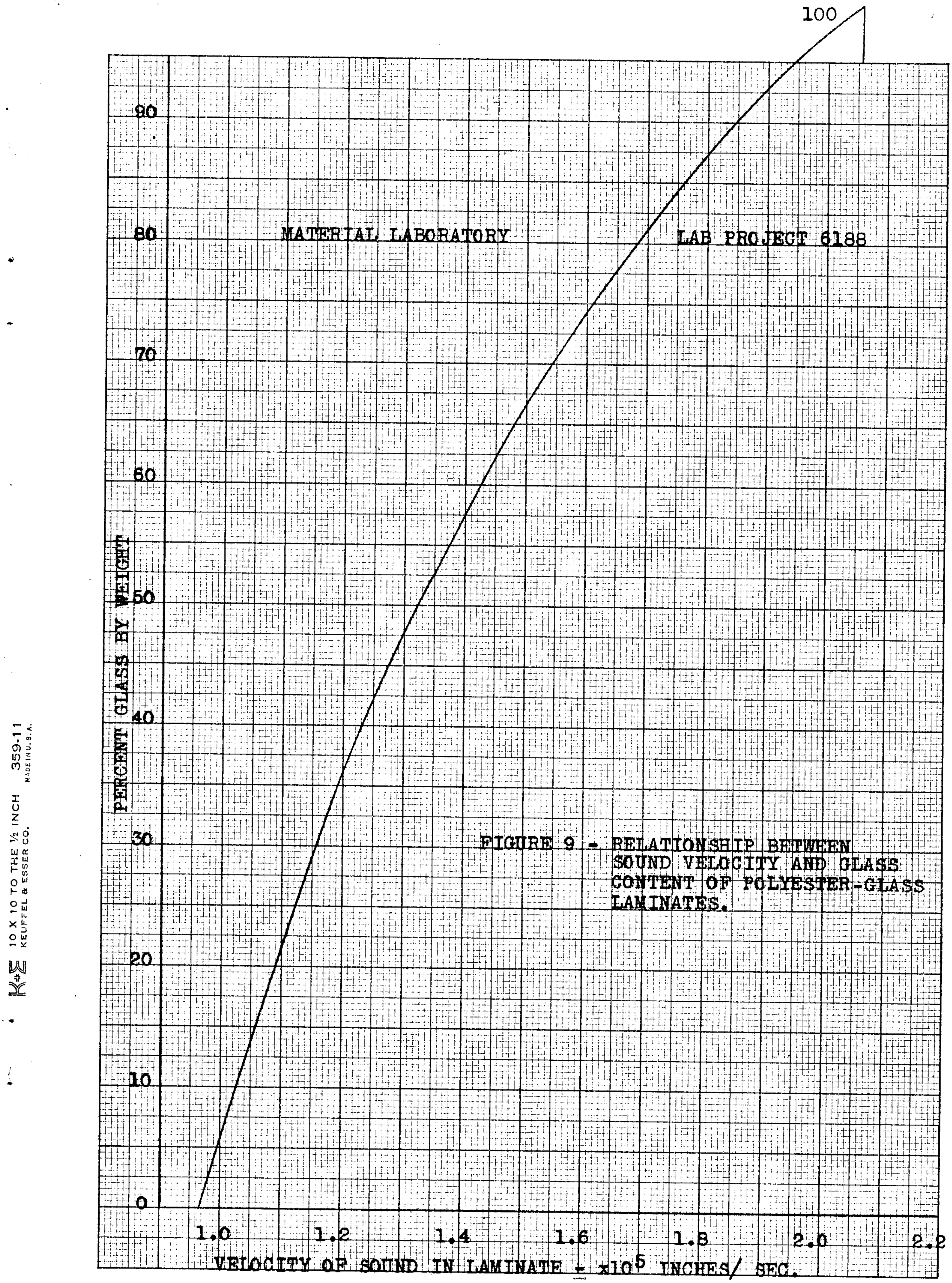


FIGURE 9 - RELATIONSHIP BETWEEN SOUND VELOCITY AND GLASS CONTENT OF POLYESTER-GLASS LAMINATES.

APPENDIX A

Subj: Trip report

Person Making Visit: Walter Hand, Supervisory Electrical Engineer
Code 948, Material Laboratory

Place Visited: Branson Instruments, Incorporated
37 Brown House Road
Stamford, Connecticut

Dates of Visit: June 7, 8 and 9, 1960

1. PURPOSE

To attend the "Sonoray" Training Course given by Branson Instruments on the application and operation of their ultrasonic flaw detecting instrument. The knowledge gained is expected to be used to carry out Lab. Project 6188 on the non-destructive testing and inspection of reinforced plastic end-items for Naval applications.

2. BACKGROUND

Lab. Project 6188 authorized the Laboratory to investigate the problem of evaluating the quality and structural soundness of glass-reinforced plastic items such as boat hulls, fairwaters, water and fuel storage tanks, etc. The Bureau forwarded for evaluation an instrument developed by Battelle Memorial Institute for this application which operates on dielectric principles. The Laboratory found the instrument to be extremely limited in its ability to perform its intended function due to non-linear response, short depth of penetration and inability to distinguish among various types of defects and variations in thickness. Since these shortcomings are inherent in its operating principles, further work with the Battelle instrument is not believed warranted at present and has been postponed until other types of recently developed non-destructive test instruments have been investigated. From a study of literature and from discussions with non-destructive testing experts, the most promising and versatile of these appears to be the pulse-echo type of ultrasonic tester.

In a visit to the Lycoming plant of the Avco Corporation where reinforced plastic heat shields for space vehicles are tested and assembled it was found that the bulk of non-destructive testing of these items is performed with ultrasonic instrumentation, as described in the "Report of Travel" to Lycoming on 25 April 1960. In addition, samples of reinforced plastic materials, measured by Branson Instruments Company representatives using their "Sonoray" ultrasonic tester showed promising results for flaw detection and thickness gauging. It was decided to continue this approach and an order has been placed for the two month rental of a "Sonoray" instrument and associated transducers. To acquire the proper techniques for using this instrument and to learn the various ways in which the "Sonoray" may be applied to non-destructive testing, a three day training course given at Branson Instruments was attended.

3. RESULTS OF VISIT

The training course covered various aspects of pulse-echo and through transmission testing both in theory and practice. The details of the course are too extensive to be covered adequately in a report of this nature. A good reference test for this information is the "Nondestructive Testing Handbook" edited by Robert C. Mc Master, Ronald Press Company.

The course stressed metallurgical testing as the prime application of the instrument and was the specific interest of the majority of the students. It is only recently that plastics have been used in applications critical enough to warrant the expense of non-destructive inspection (nose cones and heat shields for space vehicles). Thus, there is extremely little background information available regarding this aspect of ultrasonic testing. This does not mean that ultrasonic testing is unfeasible, but rather that further development is required to make this form of testing of practical value.

The course served to acquaint the student with numerous ultrasonic testing techniques, how and where they are applied, and how to interpret the information derived. Considerable experience and double checking is required to distinguish a true flaw response from wave transformation effects which may produce similar responses. Techniques for avoiding this pitfall were studied.

4. CONCLUSIONS

At this stage, there is insufficient experience accumulated to state whether the objectives of the program will be accomplished. The outlook for at least partial success is favorable and the pursuit of ultrasonic non-destructive testing of reinforced plastics appears justified.

APPENDIX B

Subj: Trip Report

Person Making Visit: Walter Hand, Supervisory Electrical Engineer
Code 948, Material Laboratory

Place Visited: Avco Research and Advanced Development Laboratories
Wilmington, Massachusetts

Date of Visit: 21 June 1960

Person Consulted: Mr. C. H. Hastings, Leader
Non-destructive Test Development Group
Materials Department

1. PURPOSE

To obtain information on methods and instrumentation used in the non-destructive testing of reinforced plastic components of space vehicles. The information and knowledge gained are intended to be applied to related Naval problems in testing and inspection of reinforced plastic end-items such as submarine fairwaters, boat hulls, mine-sweep floats, etc. Of particular interest is the application of ultrasonic testing techniques to reinforced plastic materials.

2. BACKGROUND

In the visit to the Avco Lycoming Division on this subject on 25 April 1960 it was strongly recommended by their testing personnel that Mr. C. H. Hastings of the Avco Research and Advanced Development Division be consulted for the most advanced information on this subject. Mr. Hastings, as Group Leader for non-destructive test development of the Avco RAD Materials Department and as Chairman of the Northeastern Chapter of the Society for Non-destructive Testing is one of the foremost authorities on this subject.

3. RESULTS OF VISIT

The discussions with Mr. Hastings on the application of non-destructive testing to reinforced plastics, and particularly the use of ultrasonics were informative. They may be summarized as follows:

a. Ultrasonics has been the most fruitful approach to the non-destructive testing of reinforced plastics.

b. A thorough understanding of the physical principles involved is required for the proper application of ultrasonic testing and for the correct interpretation of the results obtained.

c. The Branson "Sonoray 5" ultrasonic tester was stated to be the best suited commercial instrument presently available for accomplishing the objectives of this program.

d. The use of acoustic transformers attached to transducers and the incorporation of tuned preamplifiers were discussed and demonstrated to be beneficial in improving the overall response of the ultrasonic system.

e. A prime objective of non-destructive testing should be the discovery of defects in the earliest possible stages of processing to minimize financial losses due to rejections. This would include quality control of raw materials and close processing controls. If this were accomplished satisfactorily, a minimum of end-product inspection would be required. In the present state of reinforced plastics manufacture this ideal is rarely accomplished, necessitating considerable final inspection. The results of final inspection should lead to correction of processing errors which in turn should reduce the amount of final inspection required.

f. At present, there is no one instrument capable of making all the non-destructive measurements required to assure satisfactory end-items. As the need for specific functional instruments becomes clarified, there is no doubt that they will eventually be developed.

g. Supplementary testing, such as determination of dielectric constant, dissipation factor and capacitance comparison with standards are being employed for quality control of both raw materials and finished products. This method is not being used or considered feasible for flaw detection.

h. Ultra high frequencies such as used in radar are being considered for flaw detection to supplement ultrasonics. This approach is still in the experimental stage and no specific results have as yet been obtained. This approach is particularly well suited for radome testing and is being used by Hughes Aircraft for this application.

4. CONCLUSIONS

The information obtained in the discussions described and in consultations with the Branson Instrument Company and the Lycoming Division of Avco have indicated that ultrasonics offers the best approach to non-destructive testing of reinforced plastics. Accordingly, it is planned to set up a Laboratory program to determine the capabilities and limitations of this type of instrumentation using the "Sonoray 5" ultrasonic tester as a well qualified instrument for accomplishing this.

APPENDIX C

SPECIFICATIONS

Sonoray Model 5

ELECTRICAL and PHYSICAL SPECIFICATIONS

Test Range	2" to 40 feet in steel, full-scale
Range Delay	0 to 10 feet in steel
Frequency Range	0.4 to 10.0 mc/s
Transducers	Branson Type ZS (contact) and ZT (immersed); any frequency between 0.4 and 10.0 mc/s, in several types of mounting
Display	A-scan, 5" C-R Tube video trace
Time Marker	Pyramid-wave marker superimposed on base line, continuously variable from less than 1/2" to more than 3 feet per cycle in steel
Pulse Repetition	Continuously variable from less than 100 to more than 600 cycles per second (other ranges also availabe).
Loop Gain	Better than 100 db, with calibrated continuously-variable coarse and fine controls.
Transducer Cable	Coaxial, type RG 62/u, any length from 3 to 100 feet, BNC connectors on both ends. On special order, lightweight "Microdot" cable No. 93-3913 available in lengths up to 20 feet.
Power Input	115 V 60 C, single-phase, 175 Watts maximum
Dimensions	11" high, 7 5/8" wide, 20 1/4" deep
Weight	37 pounds

APPENDIX C

PERFORMANCE SPECIFICATIONS

Sensitivity	At substantially less than full gain, gives a full scale signal, of 1/64" flat-bottom hole at 2.25 and 5 mc/s and of a 2/64" flat-bottom hole at 1.0 mc/s
Linearity	Vertical, proportional to flaw signal within ± 2%; Horizontal, proportional to time within ± 2%
Dynamic Range	Better than 50-1 (with signal from #1 Alcoa Test Block clearly defined, signal from #7 Alcoa Test Block is less than full scale.)
Price	$2,750.00 w/1 Type ZS transducer Transducers - $100.00 - $150.00 each

DISTRIBUTION LIST

Chief, Bureau of Ships
Department of the Navy
Washington 25, D.C.
(Code 335, 4 copies)
(Code 634C, 11 copies)

Chief, Bureau of Yards and Docks
Department of the Navy
Washington 25, D.C.

Engineer Research and Development
Laboratories
Corps of Engineers
U.S. Army
Fort Belvoir, Virginia
(Mr. P. Mitten

Office of the Chief of Ordnance
(ORDTB-Materials
Department of the Army
Washington 25, D.C.

Commanding General
Wright Air Development Center
(WCLTR-4)
Wright-Patterson Air Force Base, Ohio

Commander, Puget Sound Naval Shipyard
Code 370
Bremerton, Washington

Commander
Norfolk Naval Shipyard (Code 350)
Portsmouth, Virginia

Commander
Boston Naval Shipyard
Boston, Massachusetts
(Mr. B.H. Tytell)

Commander
Charleston Naval Shipyard (Code 260)
U.S. Naval Base
Charleston, South Carolina

Commander
Long Beach Naval Shipyard
Long Beach, California

ASTIA (FINAL REPORTS ONLY) - 10 copies

Commander
Pearl Harbor Naval Shipyard (Code 251)
Navy No. 128 Fleet Post Office
San Francisco, California

Commander
Philadelphia Naval Shipyard
Naval Base
Philadelphia 12, Pennsylvania

Commander
San Francisco Naval Shipyard
San Francisco 24, California

Commander
Mare Island Naval Shipyard (Code 250)
Vallejo, California

U.S. Naval Ordnance Laboratory
Silver Spring, Maryland
(Dr. A. Lightbody)

Chief, Bureau of Weapons (RMMA)
Department of the Navy

Commandant
U.S. Coast Guard
Washington 25, D.C.

Director
Signal Corps Engineering Laboratories
Squier Signal Laboratories
Fort Monmouth, New Jersey
(Mr. E. Beekman)

Commander
Portsmouth Naval Shipyard (Code 250)
Portsmouth, New Hampshire

Engineering Experiment Station
Annapolis, Maryland

Plastec
Picatinny Arsenal
Dover, New Jersey

Reference BUSHIPS Instruction 5510-5A
Ch. 1, Ser 312-5 of 18 March 1959